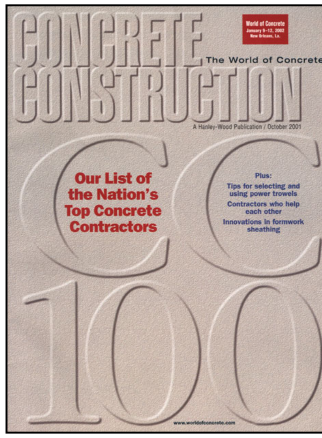
Are Temperature Requirements in Mass Concrete Specifications Reasonable?



Used with permission

Concrete Perspectives

Concrete Construction Magazine October 2001

pp. 68-70

To prevent thermal cracking, most state departments of transportation cite a maximum temperature differential requirement for mass concrete in bridge piers. This requirement can create headaches for the contractor who hasn't fully considered how to deal with it.

We asked Martha VanGeem, principal engineer with Construction Technology Laboratories (CTL) in Skokie, Ill., and Ralph Browne, bridge field engineer with the Texas Department of Transportation (TxDOT) Bridge Division in Austin to address this issue. In this discussion they tell us what can be done to provide improved and practical specifications for durable mass concrete construction.

Why does thermal cracking occur in bridge pier construction?

VanGeem: Concrete in bridge piers has the potential to crack when temperature gradients within the concrete cause thermal stresses to exceed the tensile strength. Concrete generates heat as it sets and gains strength. The more cementitious materials in the concrete, the warmer the concrete gets. In large structures such as bridge piers, temperature gradients develop because the concrete surfaces are cooled by the air or water much faster than the core.

Browne: We are quite concerned about the potential loss of service life in our bridges due to thermal cracking. Cool weather and placement of part of a bridge element in water create the greatest challenges to controlling the temperature differential and reducing early age thermal cracking.

What do current bridge specifications for mass concrete require?

Browne: The present TxDOT specification allows only a 35º F temperature difference between core and surface. This tolerance can be very difficult to maintain, and a significant number of concrete mix designs must be batched to find the constituents that provide the proper strength while maintaining the desired set time, durability, and temperature control.

VanGeem: State DOTs often have standard mix designs from which contractors can choose, and they often require 600 pcy of cement or more. DOTs also often limit the temperature difference to 35º F. Many contractors do not anticipate that it's nearly impossible to meet both requirements unless they use cooling measures or surface insulation.

Problems have increased in recent years for several reasons. First, placing larger structures faster allows less time for the concrete core to cool. The cooling rate increases exponentially with thickness. So, a 6-inch-thick footing will release the heat generated within hours while a 5-foot thick footing could take weeks. A second problem is that higher cement contents are being specified to "ensure durability"—a "more-is-better" syndrome. Some specifiers and contractors think that high cement contents will improve concrete durability and make up for variability in control during placement. Third, in order to meet specified maximum water-to-cement ratios, when more water is added, more cement must be added. All three of these factors lead to higher temperatures, which lead to higher temperature gradients in the concrete and a greater potential for thermal cracking.

Is the specified 35ºF maximum temperature a reasonable limit?

VanGeem: It depends. The actual maximum allowable temperature difference can be calculated and depends on the tensile strength of the concrete and the restraint. Tensile strength is dependent on the concrete's age, thermal expansion, modulus of elasticity, and creep. The surface of the concrete is restrained by the warm expanding concrete core, which does not allow the surface to shrink as it cools. The bottom of the concrete experiences restraint from the base material, which does not allow the concrete to freely shrink as it cools. These factors vary from placement to placement, so 35ºF does not apply to all cases. In many situations, it is overly restrictive to limit the temperature difference to 35°F; thermal cracking may not occur even at higher temperature differences. Whereas, in other cases significant thermal cracking may occur even when the temperature difference is less than 35°F.

What remedies do we have as a result of current research and construction experience?

Browne: Currently, TxDOT and the Center for Transportation Research at the University of Texas are working on a research project for concrete

> The 35°F temperature differential rule of thumb is arbitrary and should not be required in the specification. – Martha VanGeem, PE

pavements; their findings may cross over to mass concrete applications. Traditionally, we have controlled early-age thermal cracking by limiting the maximum temperature rise and the maximum temperature difference within the structure during hydration. Tests on restrained thermal specimens have shown that besides temperature change, all the factors that influence strength and stress development must be considered. The risk of early-age thermal cracking may be minimized through the use of concrete mixtures with: (1) low coefficient of thermal expansion, (2) crushed aggregates with rough surfaces that provide increased tensile strength, and (3) certain types of fly ash and GGBFS (ground granulated blast-furnace slag) that retard and reduce the rate of hydration. Also, computerized simulation techniques are becoming more reliable and user-friendly, and their use in future specifications is inevitable. These techniques will help evaluate plans for crack avoidance.

VanGeem: At CTL we encourage owners and contractors to calculate temperature values. If the maximum predicted temperature difference exceeds the allowable temperature difference (indicating the potential for cracking), we recommend the following remedial measures:

- Use less cement. Designers often specify a concrete compressive strength of 4000 psi for large piers, yet the concrete placed is reaching 7000 psi in 7 days, an indication that more cement is being used than is needed.
- Allow the design strength to be met in 56 rather than 28 days, allowing less cement to be used.
- Use fly ash or GGBFS as a replacement for a portion of the cement. Class F fly ash generates about half as much heat as cement and is often used at a replacement rate of 15% to 25%. GGBFS is often used at a replacement rate of 65% to 85% to reduce heat.
- Use a coarse aggregate with a relatively low coefficient of thermal expansion such as limestone or granite. This has the effect of increasing the maximum allowable temperature difference.
- Precool the concrete. This will reduce the maximum concrete temperature and temperature difference. Methods to precool concrete include shading and sprinkling of aggregate piles (as appropriate), use of chilled mix water, replacement of mix water by ice, and use of liquid nitrogen. Efforts to cool aggregates have the most pronounced effects on the concrete temperature because they represent 70% to 85% of the weight of the concrete.
- Negotiate with the owner to accept a calculated maximum allowable difference as the criteria rather than the arbitrary 35ºF limit.

If these measures do not satisfy the criteria, we generally suggest covering the concrete with insulating blankets. This keeps the surface warmer and prevents cracking. However, since the blankets slow down the rate of cooling, they often need to be kept in place for weeks, which can prolong construction schedules.

Are current specifications for mass concrete construction for transportation structures appropriate?

Browne: We believe our current specification is complicated, since it makes the cost of cooling controls a subsidiary part of the concrete bid. Many contractors miss this. We are proposing the creation of a new pay item for mass concrete, so that our contractors are aware that extra measures are required. This new pay item should alert our contractors to the temperature controls needed and enable them to capture those costs. Additionally, our current specification requires a heat flow analysis to be submitted to the engineer. We are finding that the submitted analyses are not very accurate, and a limited number of engineers can perform the analysis quickly. Therefore, we will be modifying our specification to allow the series of simple algebraic equations found in the PCA Design and Control of Concrete Mixtures, Thirteenth Edition, Chapter 15. We believe these two changes will help our contractors price the concrete appropriately, and more easily choose heat control methods.

VanGeem: We agree that the current specifications are difficult to work with. Contractors often come to us right before a pour asking us to perform calculations for them to submit. Quite often the calculations reveal that the mix won't meet the specification, but by this stage in the project, time and money aren't available to reconsider the mix or to use insulating blankets. So, contractors must be made more aware of the significance of the thermal cracking portion of the specification.

The 35º F rule of thumb is arbitrary and should not be the requirement in specifications. Specifications should require the maximum allowable temperature difference to be calculated following the guidelines in ACI 207.2R "Effect of Restraint, Volume Change, and Reinforcement on Cracking of Mass Concrete," and the maximum temperature and temperature difference to be calculated in accordance with the finite difference method in ACI 207.1R "Mass Concrete." The equation in the PCA publication is too simplistic for most situations; it does not consider thicknesses or shape of a structure or variations in heat generated among cementitious materials.

> The present TxDOT specification allows only a 35°F temperature difference between core and surface temperatures. – Ralph Browne